

# DISTRIBUTION AND ABUNDANCE OF COMMON DOLPHIN, *DELPHINUS DELPHIS*, IN THE SOUTHERN CALIFORNIA BIGHT: A QUANTITATIVE ASSESSMENT BASED UPON AERIAL TRANSECT DATA

THOMAS P. DOHL, MICHAEL L. BONNELL, AND R. GLENN FORD<sup>1</sup>

## ABSTRACT

On 35 aerial transect surveys of the Southern California Bight, 157 sightings of common dolphin, *Delphinus delphis*, schools were observed and mapped for distributional analysis. Sightings were pooled into 30' of latitude by 30' of longitude sampling quadrats, and density estimates were obtained by fitting a Fourier series to a frequency distribution of perpendicular sighting distances. Two distinct seasonal distributions are represented by density contour maps: a winter-spring distribution when schools were confined to the easternmost and warmest waters of the area, and a summer-autumn distribution when schools were widespread. Mean seasonal population estimates were 15,448 for winter-spring and 57,270 for summer-autumn (cv of 0.36 and 0.17, respectively). During the warmer water months, the common dolphin population expands its use of the Southern California Bight. They enter from the south, apparently following the major undersea ridges and escarpments, and flow through the Southern California Bight in a generalized counterclockwise fashion. Observational evidence suggests that there is mixing of both the nearshore and pelagic forms of this species in the offshore waters over the Santa Rosa-Cortés Ridge and Patton Escarpment.

The common dolphin, *Delphinus delphis*, is the most abundant cetacean in the waters of the Southern California Bight (SCB). On an annual basis the numbers of common dolphins exceed, on average, the combined total of all other cetaceans in this area by 2.75 times (Dohl et al. 1980).

Common dolphins inhabit subtropical waters of Mexico and the SCB throughout the year (Norris and Prescott 1961). Density estimates for this species and other dolphins (*Stenella* sp.) in waters offshore of Mexico and Central America were calculated by the National Marine Fisheries Service in 1974 (Smith 1981). The distribution of common dolphins in the eastern parts of the Southern California Bight was described by Evans (1975).

In order to understand the role of the common dolphin in the ecology of the SCB and to understand when and where this population is mostly vulnerable to human activities, we have constructed a spatial-seasonal distributional model with two aims: 1) to generate population estimates for the entire area and 2) to describe the general features of seasonal distribution patterns. This is the first study to examine the spatial heterogeneity of common dolphin distribution in the SCB and to generate confidence limits for density and seasonal mean population size estimates.

From April 1975 through March 1978, nearly 110,000 nmi (200,000 km) of combined aerial and ship surveys were conducted within the SCB for the Department of the Interior, Bureau of Land Management (now the Minerals Management Service). During this marine mammal and seabird study, a total of 505 schools of 134,675 *Delphinus delphis* were recorded.

This paper is primarily concerned with one subset of the 3 yr, common dolphin sighting data base. To avoid the statistical pitfalls of pooling data obtained from a variety of platforms performing their missions at different speeds, at different altitudes, and over varying portions of the study area, we restricted these analyses to 35 monthly flights flown at 1,000 ft above sea level (ASL). Each of these surveys required about 15 overwater flight hours and covered about 1,350 nmi (2,500 km) of track-line. All species of cetaceans encountered were recorded as to location, number, behavior, direction of movement, and number of juveniles. Common dolphins were encountered 157 times in this flight series, for a total of 46,153 animals or 69% of all cetaceans observed.

The results of the distributional study and accompanying figures were derived from the 1,000 ft ASL aerial survey data defined above. However, material in the Discussion section draws upon observations made from all survey platforms used during this study.

<sup>1</sup>Institute for Marine Sciences, University of California, Santa Cruz, CA 95064.

## METHODS

Aerial surveys were flown at an altitude of 1,000 ft ASL (328 m) at about 90 kn (167 km/h) in a high-wing, twin-engine Cessna<sup>2</sup> 337. The crew consisted of a pilot and three experienced marine mammal observers, one acting as recorder. Surveys were flown along 15 parallel, predetermined tracklines, separated by 15 nmi and extending from the shore to a maximum distance of 100 nmi (185 km; Fig. 1). Tracklines were oriented from northeast to southwest and were roughly perpendicular to the shoreline, as well as to most major features of submarine topography in the study area. Whenever possible, all transect lines were surveyed on each 3-d flight. Transect lines were not replicated on a single survey, nor were they flown in a predetermined order or direction. The first line flown on a given day was occasionally dictated by weather or military activity in the area; subsequent lines were chosen to optimize coverage and simplify logistics.

Observers searched unbounded corridors on each side of the aircraft trackline. Sightings were recorded

and coded for computer entry at the time of occurrence. The aircraft was diverted to circle those schools located off the trackline for positive identification, animal count, and photographs. The total animal count recorded for each school was a consensus of the observers on board, derived from multiple orbits of the school. Any additional sightings obtained while "off transect" were not included in later density calculations due to the possibility that the secondary sighting was prompted by the first. All transect segments where observer effectiveness might have been hampered by fog and/or sea state were deleted from the data base; only transect segments where visibility exceeded 1 nmi and the sea state was Beaufort 3 (few, scattered whitecaps) or less were retained.

Aerial photographs were used to validate observer estimates of school size. The aerial photographs were taken on 9" × 9" film from a vertically mounted camera and on 4" × 5" and 35 mm films in handheld cameras for oblique views. The large, 9" × 9" vertical photographs soon proved to be the most useful and were used almost exclusively for count verification. Observer counts and film counts on average-sized schools (up to 100 animals) varied only slightly, but not in a consistent manner. The 3-5%

<sup>2</sup>Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

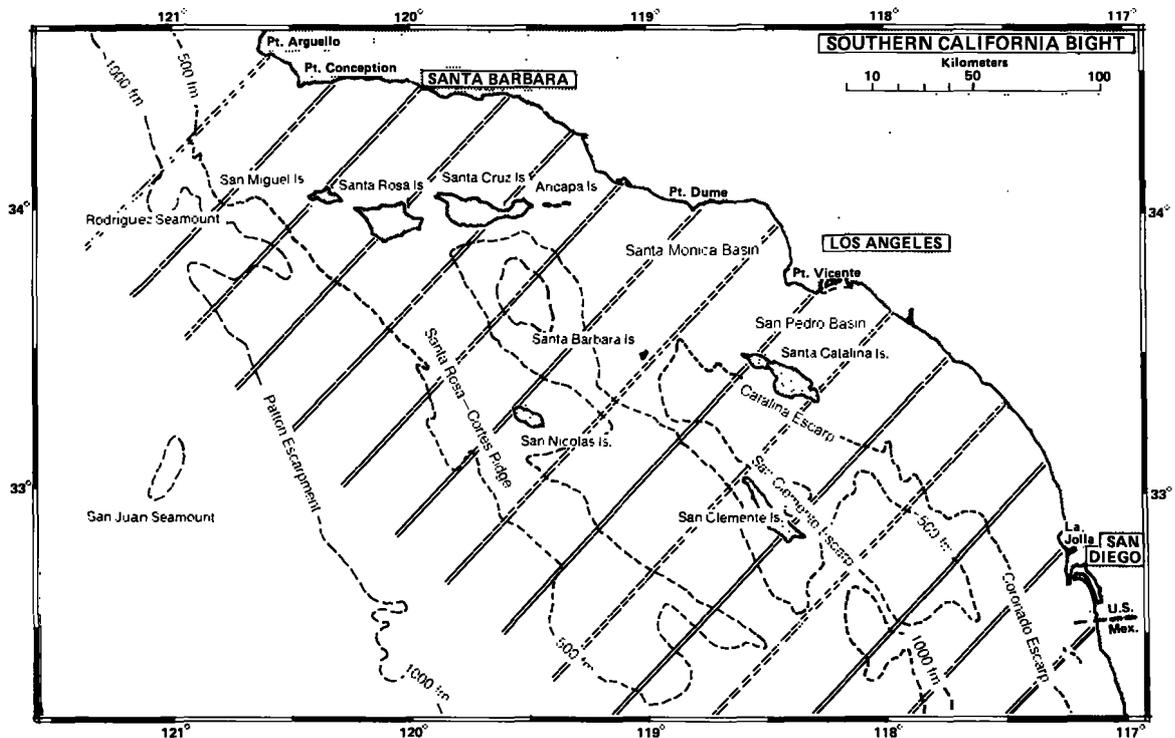


FIGURE 1.—Map of the Southern California Bight study area showing aerial survey tracklines.

variations in counts occurred randomly, with no pattern to indicate in which method the higher counts would occur. Small schools of <100 animals represented most of the sightings (53%). In medium-sized schools, up to 300 animals, the variation was higher (about 11%), and the photographs indicated probable observer underestimation in 62% of the counts. The largest underestimates occurred in large schools, >300 animals, and were found in 76% of the observer counts. These underestimates ranged up to 30% in some circumstances. Within the large-school category, two subcategories became evident: 1) Dispersed schools with multiple discrete subgroups of animals gave the observers less of a problem than 2) the tightly grouped, rapidly moving, compact schools. The dispersed large schools yielded underestimate values in the range of 14-16%, while the compact, large groups were usually 21-23%. Extremely large schools of over 1,000 animals were responsible for the highest error values of up to 30%; these schools accounted for only 6.6% of total sightings.

Generally, we found that aerial estimates were lower than numbers based on photographs and that the larger the school, the higher the difference. We attribute some of the difference to the time lag between when the count was made while circling the school and the photo run over the center of the school. Results of photo runs made either before or after the counting effort did not vary significantly, but occasionally, continued circling scattered larger schools into several smaller subgroups.

Sea surface glare affected observation efficiency to some degree on about 10% of all survey days. Due to the orientation of transect lines, glare conditions could impair the search ability of only the left-side observer on southwest-bound legs (up to 26% of total search effort per survey day). Holt (1984<sup>3</sup>) found density estimates of dolphin schools to be 39% lower under poor sun conditions than during good sun conditions. Using his figure, we calculate that our overall seasonal density estimates might be low by about 1%. Because of the lack of any systematic bias resulting from glare affecting density estimates in one particular region or season more than another, we made no corrections to adjust for this slight underestimate.

The perpendicular distance from the trackline to the sighting was calculated from the declination angle obtained using a hand-held inclinometer. Per-

pendicular distances were recorded for 112 sightings of common dolphin schools, representing 74.2% of all sightings used in density calculations.

### Distributional Model

Inspection of the first year's common dolphin sighting numbers and plots of monthly distribution indicated seasonal fluctuations of residency within the Southern California Bight.

Examination of the 3-yr database showed two distinct seasons of occupancy for the species in the SCB (Fig. 2). A comparison of the two sets of data on a monthly basis show a significant statistical difference ( $F_{(1,34)} = 7.66, P < 0.01$ ). In view of these observations, two seasons were defined for the development of the distributional model: a summer-autumn season (July through December) when common dolphin sightings were widespread in the SCB, and a winter-spring season (January through June) when most schools were confined to the southeastern portion of the surveyed area. Common dolphin sightings were assigned by their latitude and longitude to 30' × 30' grid-cells (sampling quadrats) centered on degree and half-degree lines of latitude and longitude. Data were pooled to provide seasonal estimates of common dolphin abundance for each 30' × 30' grid-cell. The estimate of density of groups in cell  $i$ ,  $D_i$ , was calculated from the relationship:

$$\hat{D}_i = n_i \hat{f}(0)/2L_i \quad (\text{Burnham et al. 1980}) \quad (1)$$

where  $n_i$  is the number of groups encountered,  $\hat{f}(0)$  is the probability density function of perpendicular distances evaluated at the  $y$ -intercept, and  $L_i$  is the sum of all transect lengths in cell  $i$  contributing to the seasonal estimate. The value of the  $\hat{f}(0)$  term was calculated using the nonparametric Fourier-series estimator of Crain et al. 1978 (see Burnham et al. 1980 for a complete discussion of this estimator). Computations were made employing the program TRANSECT (Laake et al. 1979). For calculation of the  $\hat{f}(0)$  term, the perpendicular distance of each sighting was reduced by one-half the width of the exclusion area under the aircraft, where visibility was obstructed by the fuselage (total exclusion area = 530 ft at 1,000 ft ASL). This approach, in effect, moves the transect centerline outboard to the point of nearest possible sighting distance—a point where it is assumed that all animals present will be seen and counted. The question of how to deal with the problem of restricted downward visibility and line transect theory has been considered by others; however, the best treat-

<sup>3</sup>Holt, R. S. 1984. Testing the validity of line transect theory to estimate density of dolphin schools. U.S. Dep. Commer., NOAA Admin. Rep., NMF'S-SWFC LJ-84:31, 56 p.

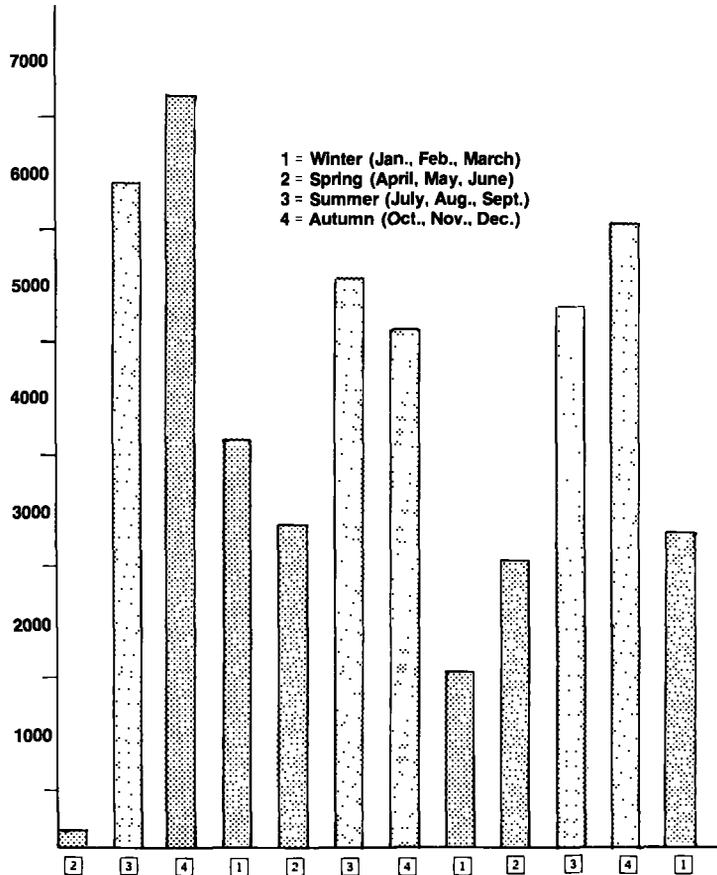


FIGURE 2.—Comparison of total counts of common dolphins on aerial surveys of the Southern California Bight by season, 1975-78.

ment of the subject, in print, is found in two papers by Leatherwood et al. (1982, 1983).

Because sample size was small in each grid-cell and in each season, data were combined to calculate a single value of  $\hat{f}(0)$ . The pooling of data was based on the assumption that the sightability of common dolphin groups did not vary between seasons or between regions of the surveyed area. Violation of this assumption would lead to biases in the estimates of relative densities between seasons or regions, although it would not necessarily effect mean population size estimates. The assumption of seasonal homogeneity was tested using a single classification ANOVA (two groups, unequal samples; Sokal and Rohlf 1969, p. 208). No significant difference between the distribution of perpendicular sighting distances collected in summer-autumn and winter-spring seasons was found ( $F_{1,111} = 2.01, P = 0.18$ ). The same test was used to compare frequency distributions with distance of sightings collected in

calmer inshore waters, with sightings collected in rougher offshore waters, since this seemed to be the most likely source of bias in sightability. No significant difference was found between the distribution of perpendicular sighting distances in the two sub-regions ( $F_{1,108} = 1.78, P = 0.20$ ).

The rescaled frequency distribution of perpendicular sighting distance is shown in Figure 3. The probability density function,  $f(x)$ , is from a three-term, Fourier-series model, which provides the best fit to these data ( $\chi^2 = 6.026, df = 3, P = 0.11$ ). Data were truncated at 6,600 ft in order to remove two extreme values. Intervals were specified, by inspection of the data, in order to smooth the function and minimize the effects of "heaping" in perpendicular distance measurements (Burnham et al. 1980, p. 47).

For estimation of common dolphin density (animals/km<sup>2</sup>) in a given grid-cell for a given season, we multiplied the density of groups in a given cell

by the mean group size throughout the SCB obtained for that season. The small sample size in any cell and the very large variability in the size of groups necessitated pooling of all sightings within a season to calculate mean group size. The mean group size in summer and autumn was  $338 \pm 38$  SE ( $n = 115$ ), while that of winter and spring was  $231 \pm 73$  SE ( $n = 36$ ). While not significantly different ( $F_{1,148} = 1.42, P > 0.25$ ), we used separate mean group size in calculations of seasonal abundance. We tested the assumption that mean group size in each season was constant throughout the SCB, using a bootstrap procedure (Efron 1982). For a given season, cell  $i$  contained  $n_i$  observations of groups of mean size  $\bar{s}_i$ . For each cell  $i$ , we randomly drew 10,000 sets of values of size  $n_i$  from the group size distribution based on all observations recorded in that season, computed the mean of this subsample, and formed a frequency distribution of these mean values. If the percentile ranking of the observed mean group size in cell  $i$  was  $>97.5\%$  or  $<2.5\%$ ,  $\bar{s}_i$  was assumed to be a nonrandom sample. For the summer-autumn season, only 1 cell of the 26 cells containing observations of common dolphins had means which differed significantly from the rest of the surveyed area. Similarly, for the winter-spring season, only 1 cell in 10 showed a significant dif-

ference from the overall group size distribution. Therefore, group size homogeneity was assumed for these data, and a single seasonal value of mean group size ( $\bar{s}$ ) was used in all calculations of cell density for each season.

If  $\hat{f}(0)$  and  $\bar{s}$  may be assumed to be homogeneous, the remaining source of between-cell variability is the density of groups. We tested the hypothesis that the density of groups is homogeneous through the SCB as follows: taking the mean number of sightings of common dolphin schools per kilometer of transect for the entire surveyed area,  $\lambda^*$ . We computed the expected number of cells containing a specified number of sightings of groups, using the formula:

[Expected number of cells with  $k$  sightings] =

$$\sum_{i=1}^{i=m} e^{-\lambda^* L_i} (\lambda^* L_i)^k \quad (2)$$

where  $m$  is the total number of cells sampled,  $k$  is the specified number of sightings of groups, and  $L_i$  is the length of trackline surveyed in cell  $i$ . The expected number of cells containing  $k$  sightings were compared with the observed number for all  $k$  using a chi-square test. No significant spatial heterogeneity was evident for data collected in summer and autumn ( $\chi^2 = 5.06, df = 5, P > 0.5$ ). However, the winter and spring distribution showed clear heterogeneity in the density of groups by cell ( $\chi^2 = 12.85, df = 3, P < 0.005$ ).

We used the method of Chernoff and Moses (1959) to place confidence limits on the estimate of the number of groups per km of transect in cell  $i$ ,  $\hat{\lambda}_i$  (see also Clopper and Pearson 1934). We used a computer program which finds a density value,  $\Gamma_1$ , such that the probability of observing  $n_i$  or more groups in a transect segment of length  $L_i$  is 0.025; this is the lower confidence bound on  $\hat{\lambda}_i$ . Similarly, we find a density value,  $\Gamma_2$ , such that the probability of observing  $n_i$  or fewer groups is 0.025; this forms the upper bound on  $\hat{\lambda}_i$ .  $\Gamma_1$  and  $\Gamma_2$  are defined as satisfying the equations:

$$\sum_{k=n_i}^{k=\infty} \frac{e^{-\Gamma_1 L_i} (\Gamma_1 L_i)^k}{k!} = 0.025 \quad (3)$$

and

$$\sum_{k=0}^{k=n_i} \frac{e^{-\Gamma_2 L_i} (\Gamma_2 L_i)^k}{k!} = 0.025. \quad (4)$$

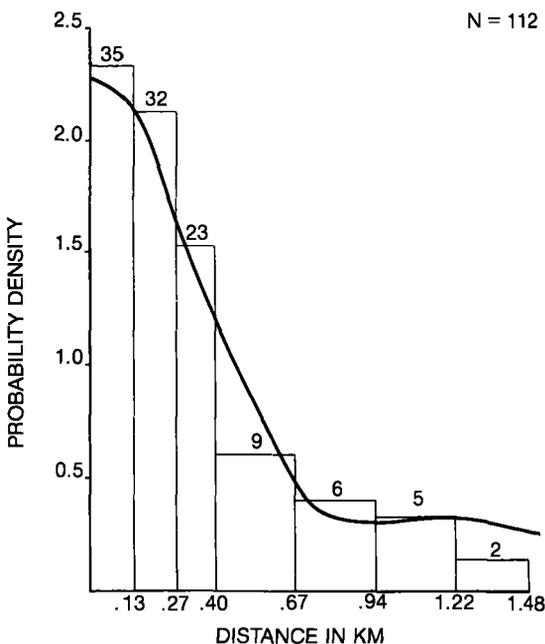


FIGURE 3.—Probability density function  $f(X)$  fit to histogram of sighting frequency and perpendicular distance (rescaled; see text).

Such confidence limits are asymmetric about  $\hat{\lambda}_i$  and decrease in size with increasing transect coverage. They have the important properties that  $\Gamma_2$ , the upper limit, tends to be large when the transect length  $L_i$  is small, even when the number of groups observed is zero, and the lower limit  $\Gamma_1$  is bounded by zero.

Population size estimates were made for each cell  $i$  in each season from the relationship  $\hat{N}_i = \hat{D}_i \cdot \bar{s} \cdot A_i$ , where  $N_i$  is the cell population,  $D_i$  is the estimated density of groups based on Equation (1) (groups/km<sup>2</sup>),  $\bar{s}$  is the seasonal mean group size, and  $A_i$  is the open-water area of cell  $i$ . Total population size in each season, ( $\hat{N}$ ), was estimated as from the sum of populations in each cell, and from the theoretical formula:

$$\hat{N} = \frac{n \cdot \hat{f}(0)}{2L} \cdot \bar{s} \cdot A \quad (5)$$

where  $n$  is the total number of groups observed,  $L$  is the total transect length,  $s$  is the seasonal mean

group size, and  $A$  is the areal extent of the study area. The variance of  $\hat{N}$  was estimated from the relationship (K. Burnham<sup>4</sup>).

$$\text{var}(\hat{N}) = A^2 \cdot \text{var}(\hat{D}_i) \quad (6)$$

where  $\text{var}(\hat{D}_i) = (\hat{D}_i)^2 \frac{\text{var}(n)}{(E(n))^2} + \frac{\text{var}(\hat{f}(0))}{(E(\hat{f}(0)))^2} + \frac{\text{var}(\bar{s})}{(E(\bar{s}))^2}$ . The variance of  $n$  was calculated assum-

ing that  $n$  had a Poisson distribution; if this assumption holds,  $\text{var}(n) = n$  (Burnham et al. 1980). The variance of  $\hat{f}(0)$  was calculated by program TRANSECT, using the method of Burnham et al. (1980). Variance of  $\bar{s}$  was estimated as the standard error of the mean group size. The formula for variance requires that  $\hat{f}(0)$  and  $\bar{s}$  be independent, an assumption that may be violated due to the differen-

<sup>4</sup>K. Burnham, Department of Statistics, School of Physical and Mathematical Sciences, North Carolina State University, Raleigh, NC 27650-5457, pers. commun.



FIGURE 4.—Common dolphin distribution in the Southern California Bight, winter and spring, 1975-78. Density contours show animals/km<sup>2</sup>.

tial sightability of large and small groups (discussed below). Because we could not be sure that the assumptions of the theoretical formula were met, we also calculated the variance of population size for the summer-autumn season, using a jackknife estimator (Miller 1974; Burnham et al. 1980). Pseudovalues of the area-wide population were generated by sequentially deleting pairs of surveys from the database. All sources of variance were considered in estimation of total variance:  $\hat{f}(0)$ , mean group size, and spatial variability of sightings. Because of the small number of perpendicular sighting distances for winter-spring season (31), we were unable to obtain a stable value of  $\hat{f}(0)$ , thus precluding the estimation of jackknife variance of that season.

Distribution maps were prepared using Surface Display Library software (Dynamic Graphics, Inc., Berkeley, CA). Contour lines, generated by linear interpolation between density values assigned to grid-cell centerpoints, were smoothed using a cubic spline function.

## RESULTS

Two distinct seasonal distributions were found for common dolphins in the Southern California Bight (SCB). In winter and spring months (January through June), common dolphin sightings were almost completely confined to the eastern part of the SCB (Fig. 4). Within the area occupied, three cells in the southernmost rank and one shore-bounded cell north of San Diego showed significantly higher density than the overall seasonal mean ( $P > 0.95$  in all cases). In summer and autumn months (July through December), common dolphin sightings were widespread from Rodriguez Seamount and the Patton Escarpment in the west to the mainland shore in the east (Fig. 5). Cell density estimates in this season were relatively homogeneous throughout the area. Only a single cell in the San Diego Basin could be shown to be significantly higher than the seasonal mean at the  $P > 0.95$  level. Nevertheless, we believe that the clustering of moderately high-density cells east of Santa Catalina and San

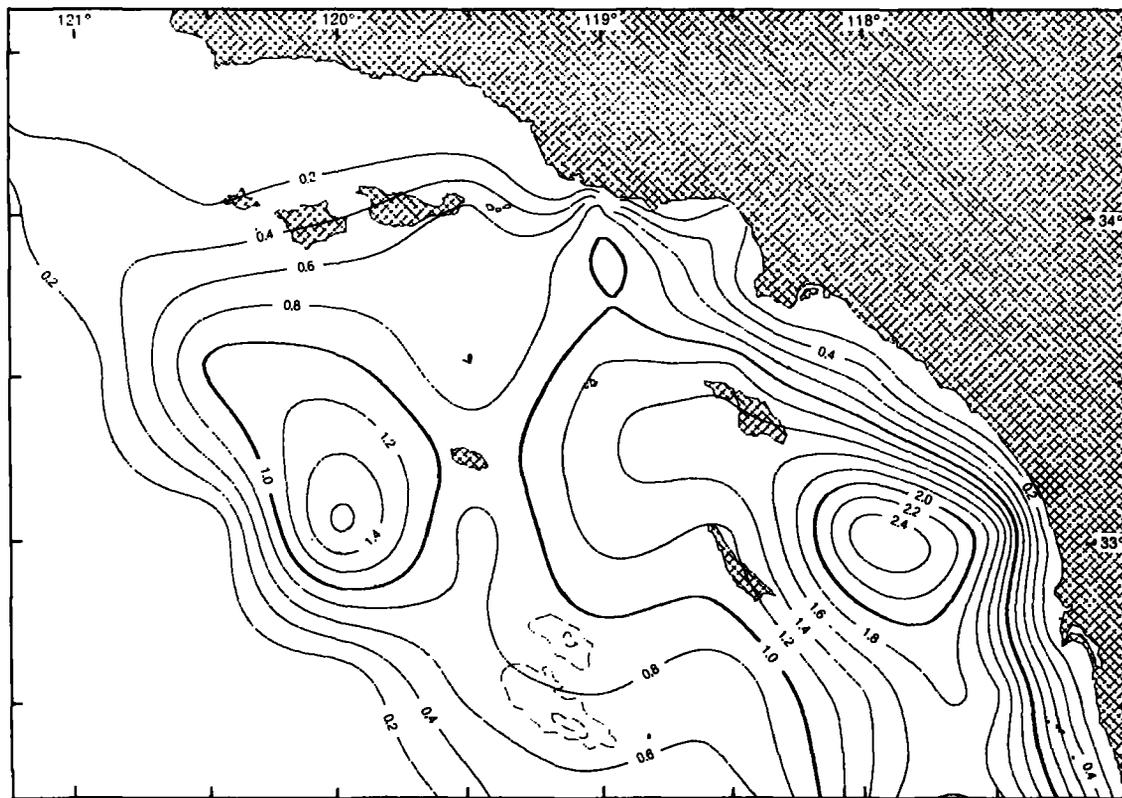


FIGURE 5.—Common dolphin distribution in the Southern California Bight, summer and fall, 1975-78. Density contours show animals/km<sup>2</sup>.

Clemente Islands and west of San Nicolas Island represents a real distributional pattern.

Cell-density estimates and 95% confidence limits are provided in Tables 1 and 2. Confidence limits were calculated considering only sampling error due to number of groups sighted (Equations (3) and (4)) and not uncertainty in  $\hat{f}(0)$  or mean group size. Sampling error associated with the number of groups sighted was the dominant source of variation in cell-by-cell estimates of density, typically exceeding variance of the  $\hat{f}(0)$  term by three times and variance associated with mean group size by five times. It should be remembered that the density estimates are mean values computed from pooled data collected over a several month period in 3 successive years.

From these density estimates, we computed

seasonal mean population size estimates. By calculating population size as the sum of the numbers in each 30' x 30' cell, we estimate a winter-spring population of 15,448 animals. This figure is a mean population occurring in the months of January through June and includes months of higher and lower numbers. Using Equation (5), we calculate a theoretical winter-spring population size of 18,933 animals. This second estimate for the SCB, based on pooled data, may be high because survey effort was 6.7% greater in the higher density parts of the study area in winter and spring. Based on Equation (6), the coefficient of variation of the winter-spring population was 36%. The coefficients of variation for number of groups,  $\hat{f}(0)$ , and mean group size were 16%, 8%, and 31%, respectively. The relatively large variability in mean group size was due to a

TABLE 1.—Relative abundance of common dolphins in the winter and spring. Mean density (animals/km<sup>2</sup>) is provided for each 30' x 30' cell; latitude and longitude indicate center point of cell. Upper and lower values are 95% confidence limits derived from the spatial variability of sightings along aerial transect lines.

	121°00'	120°30'	120°00'	119°30'	119°00'	118°30'	118°00'	117°30'
	7.41	1.71	1.33	2.42				
34°30'	0.00	0.00	0.00	0.00				
	0.00	0.00	0.00	0.00				
	3.42	1.05	0.81	0.62	0.86	1.28		
34°00'	0.00	0.00	0.00	0.00	0.00	0.00		
	0.00	0.00	0.00	0.00	0.00	0.00		
		5.32	1.19	0.90	1.05	0.48	1.09	1.81
33°30'		0.00	0.00	0.00	0.19	0.10	0.43	0.00
		0.00	0.00	0.00	0.05	0.00	0.19	0.00
			4.89	1.71	0.76	1.14	1.38	2.00
33°00'			0.00	0.48	0.00	0.33	0.48	0.95
			0.00	0.14	0.00	0.10	0.19	0.48
				1.24	0.71	1.95	2.57	2.80
32°30'				0.00	0.00	0.76	1.09	1.38
				0.00	0.00	0.33	0.48	0.67

TABLE 2.—Relative abundance of common dolphins in the summer and fall. Mean density (animals/km<sup>2</sup>) is provided for each 30' x 30' cell; latitude and longitude indicate the center point of cell. Upper and lower values are 95% confidence limits derived from the spatial variability of sightings along aerial transect lines.

	121°00'	120°30'	120°00'	119°30'	119°00'	118°30'	118°00'	117°30'
	3.53	1.45	1.32	3.12				
34°30'	0.00	0.00	0.00	0.05				
	0.00	0.00	0.00	0.14				
	1.80	1.04	1.25	1.52	2.15	2.08		
34°00'	0.35	0.21	0.35	0.62	0.83	0.35		
	0.07	0.07	0.07	0.28	0.35	0.07		
		5.82	2.70	1.73	2.70	2.15	1.25	2.56
33°30'		1.04	1.04	0.62	1.25	1.25	1.42	0.48
		0.28	0.42	0.21	0.55	0.76	0.14	0.14
			4.92	2.29	2.91	2.56	4.09	2.98
33°00'			1.66	0.76	1.32	1.25	2.56	1.66
			0.62	0.28	0.62	0.62	1.59	0.90
				2.49	2.08	1.94	3.39	3.12
32°30'				0.69	0.83	0.69	1.45	1.66
				0.21	0.35	0.21	0.62	0.90

single sighting of 2,450 animals; we choose not to treat this observation as an outlier because the occasional occurrence of very large groups is typical of this species.

For the summer-autumn season of greatest abundance, the stock size estimate based on summing individual cell populations and the estimate derived from Equation (5) were 57,270 and 46,675, respectively. The theoretical estimate based on pooled data may be low because survey effort was 7.8% greater in the lower density parts of the study area in the summer-autumn season (i.e., the offshore waters in the west). The coefficient of variation computed from the theoretical variance formula (Equation (6)) was 17%. Coefficients of variation for number of groups,  $\hat{f}(0)$ , and mean group size were 9%, 8%, and 11%, respectively. The jackknife estimator gave a higher coefficient of variation for population size of 27%. Components of this estimate for number of groups,  $\hat{f}(0)$ , and mean group size were 15%, 18%, and 14%, respectively. Differences between the two types of estimators may be due, in part, to the inherently conservative nature of the jackknife (Efron 1982), but probably result primarily from within-survey correlation of variables. In addition, the jackknife estimate of  $\hat{f}(0)$  relied on a smaller subset of sighting distances measured only during summer-autumn surveys ( $n = 81$ ).

## DISCUSSION

Even in an area as heavily utilized as the Southern California Bight, sightings of common dolphin schools are not common events. For this reason it was necessary to pool aerial survey data collected over several months in each of three years to describe their distribution in statistical terms. The two seasonal views of common dolphin distribution in the SCB are shown for contrast in Figures 4 and 5. It is apparent that the population makes seasonally greater use of the SCB in summer and autumn months. The months of greatest numbers, based on sightings per km of trackline, were September through November. During these months, the population far exceeds the mean value of 57,000 and probably approaches 100,000 animals.

A potential source of bias in our mean population size estimates was the differential sightability of groups of various sizes. The detection function for common dolphin sightings declined sharply beyond about 1,650 ft (500 m), suggesting that mostly large or conspicuous groups were seen at relatively great distances. The Fourier estimator is robust to variation in sighting efficiency (Burnham et al. 1980). For

comparison, the  $\hat{f}(0)$  term of 2.29 for common dolphins was quite close to the  $\hat{f}(0)$  estimate of 2.16 more recently obtained for 136 sightings of Pacific white-sided dolphin schools on aerial surveys offshore of central and northern California (Dohl et al. 1983). However, variable sighting effectiveness may also bias the estimation of mean group size. Holt and Powers (1982) found that smaller groups of dolphins were more likely to be missed on aerial surveys than larger groups, resulting in a 25% overestimation of mean group size. For our data on common dolphins, we did not find a significant difference in mean group size between sightings within the first 1,650 ft and beyond due to high variability in sightings size ( $213 \pm 46$  SE,  $n = 65$ , compared with  $308 \pm 49$  SE,  $n = 50$ ;  $F_{1,113} = 1.94$ ,  $P = 0.18$ ). Nevertheless, our calculations show that stratification of mean group size by distance from the trackline (<1,650 ft and >1,650 ft) would result in an 18% decrease in mean density values.

The distribution shown for summer and autumn can be viewed as a composite of monthly distributions. Common dolphin distribution expands from the southeast into the central and western parts of the SCB in late spring and early summer and recedes toward the east and south in late autumn and early winter. Common dolphin movement into and out of the SCB appears to be temperature related. As sea surface temperatures (SST) rise in late spring-early summer, animals begin to be sighted more often along the Coronado Escarpment. Peak numbers of common dolphins were found in open water regions of the SCB 3-5 wk after intrusion of the warmer waters. During cool-water months, when SSTs down to 10.0°C were recorded and the SCB-wide mean was 14.6°C, no animals were observed in waters cooler than 14.0°C.

Distributional patterns of the common dolphin within the SCB may be changing. Hui (1979) analyzed data collected on Naval Ocean Systems Center (NOSC) surveys from 1968 through 1976 and showed no common dolphin sightings north of Point Vicente (lat. 33°45'N) or west of approximately San Nicolas Island. Our surveys in summer and autumn months found 29.9% of all sightings and 30.8% of all animals occurred in the northern and western portion of the SCB—an area largely unsampled by the NOSC surveys. Hui's results agreed with those of Evan's (1975), who found only a small fraction of the total sightings recorded on aerial and shipboard surveys to occur in this northern and western portion of the SCB; however, aerial sampling effort in Evan's earlier study also favored the inshore and southern portions of the SCB.

Based upon the distribution of sightings on our bimonthly aerial surveys, movement of common dolphins into the SCB appeared to follow the network of escarpments and seamounts noted by Evans (1971). The major corridor was along the Coronado Escarpment to Thirty-Mile Bank, up to the Catalina Escarpment, around both sides of Santa Catalina Island, along the western margins of the San Pedro and Santa Monica basins to Santa Cruz and Santa Rosa Islands (Fig. 1). The population front then advanced westward along the southern margin of these islands until reaching the Santa Rosa-Cortés Ridge where it shifted south, spreading out along the western slope of this prominent underwater feature. Some elements of this influx stopped and along the way, increasing summer-autumn populations significantly in the San Pedro Channel, Gulf of Santa Catalina, and, to a lesser extent, in nearshore waters from Dana Point to La Jolla. A secondary pathway was from Forty-Mile Bank in the south, up the San Clemente Escarpment west of San Clemente Island to reach the Santa Rosa-Cortés Ridge area.

During periods of peak occupancy common dolphin sightings west of long.  $119^{\circ}\text{W}$  were distributed along the western slope of the Santa Rosa-Cortés Ridge centered at lat.  $33^{\circ}00'\text{N}$ , long.  $120^{\circ}00'\text{W}$ . As waters cooled, the distributional center shifted eastward to locate over the eastern slope of the Santa Rosa-Cortés Ridge at  $33^{\circ}00'\text{N}$ ,  $119^{\circ}20'\text{W}$ , while a smaller element moved northwesterly to a new location around  $33^{\circ}30'\text{N}$ ,  $120^{\circ}30'\text{W}$ . With continued cooling of the western waters, the majority of the animals along the eastern edge of the Ridge appeared to move southeasterly to merge with existent populations south and east of San Clemente Island. The remaining small number of animals wintering-over moved westward, centering near  $33^{\circ}00'\text{N}$ ,  $119^{\circ}30'\text{W}$ , south of San Nicolas Island.

The destination of common dolphins that moved northwesterly from the summering grounds over the western edge of the Santa Rosa-Cortés Ridge is unknown. However, several pieces of incomplete evidence lead us to believe that they are part of a "pelagic" population that returns in late autumn or early winter to offshore waters over the Rodriguez Seamount or Patton Escarpment. During several midsummer ship surveys and three aerial surveys of offshore waters over the Patton Escarpment and San Juan Seamount, we recorded sightings of large schools of robust-bodied, brilliantly marked, "pelagic" common dolphins. On two occasions, our crew on the catch boat head-netted, brought on

board, photographed, measured, tagged, freeze-branded, and released, examples of these "pelagic" animals from within schools containing predominantly the paler, smaller, nearshore variety of *Delphinus*. Ships' logs indicate that the presence of these "pelagic" animals increased with distance from shore, and percentages as high as 50% were found in mixed schools of common dolphins at the western boundary of catch trips, usually south of lat.  $33^{\circ}45'\text{N}$  and west of long.  $120^{\circ}00'\text{W}$ . West of the Patton Escarpment, mixed schools were not noted, and the few schools encountered contained only "pelagic" animals (Dohl unpubl. data).

In summary, this study establishes an extended distributional range of the common dolphin within the SCB, identifies areas of significantly greater seasonal use, and provides seasonal mean population estimates. Our results confirm the findings of earlier studies that common dolphins move into the SCB following major features of underwater topography in response to increasing seasonal water temperatures. Observations on surveys also seem to indicate that most of the population moves through the SCB in a generalized counterclockwise direction, and that the western summer-autumn population is augmented by an influx of "pelagic" animals from far offshore.

## ACKNOWLEDGMENTS

The original data for this paper were collected under contract to the University of California, Santa Cruz, from the Minerals Management Service (formerly a part of Bureau of Land Management), U.S. Department of the Interior.

The analysis of these data and the development of the distributional model described here were supported by Woodward-Clyde Consultants (WCC), Walnut Creek, CA, by a contract from the Minerals Management Service, Department of the Interior.

We are grateful to the many individuals involved in the collection of these data: J. D. Bryant, R. C. Guess, J. D. Hall, L. J. Hobbs, M. W. Honig, K. S. Norris, and P. N. Sund. We also thank T. P. Winfield and R. K. Christiansen at WCC for technical assistance, and particularly K. P. Burnham, T. D. Smith, and R. S. Holt for valuable assistance and comments on the manuscript.

## LITERATURE CITED

- BURNHAM, K. P., D. R. ANDERSON, AND J. L. LAAKE.  
1980. Estimation of density from line transect sampling of biological populations. *J. Wildl. Manage. Monogr.*

- 72, 202 p.
- CHERNOFF, H., AND L. E. MOSES.  
1959. Elementary decision theory. John Wiley and Sons, Inc., New York, NY.
- CLOPPER, C., AND E. S. PEARSON.  
1934. The use of confidence or fiducial limits illustrated in the case of the binomial. *Biometrika* 26:404-413.
- CRAIN, B. R., K. P. BURNHAM, D. R. ANDERSON, AND J. L. LAAKE.  
1978. A Fourier-series estimator of population density for line transect sampling. Utah State Univ. Press, Logan, 25 p.
- DOHL, T. P., K. S. NORRIS, R. C. GUESS, J. D. BRYANT, AND M. W. HONIG.  
1980. Cetacea of the Southern California Bight. Part II of summary of marine mammal and seabird surveys of the Southern California Bight Area, 1975-1978. Final Report to the Bureau of Land Management, 414 p. [Available at U.S. Dep. Commer., Natl. Tech. Inf. Serv., Springfield, VA as NTIS Rep. #PB81248189.]
- DOHL, T. P., R. C. GUESS, M. L. DUMAN, AND R. C. HELM.  
1983. Cetaceans of central and northern California, 1980-1983: Status, abundance, and distribution. Final report to the Minerals Management Service, Contract #14-12-0001-29090, 284 p.
- EFRON, B.  
1982. The jackknife, the bootstrap, and other resampling plans. The Society for Industrial and Applied Mathematics, Philadelphia, PA.
- EVANS, W. E.  
1971. Orientation behavior of delphinids: radio-telemetric studies. *Ann. New York Acad. Sci.* 188:142-160.  
1975. Distribution, differentiation of populations, and other aspects of the natural history of *Delphinus delphis Linneaus* in the northeastern Pacific. Ph.D. Thesis, Univ. California, Los Angeles, 164 p.
- HOLT, R. S., AND J. E. POWERS.  
1982. Abundance estimation of dolphin stocks involved in the eastern tropical Pacific yellowfin tuna fishery determined from aerial and ship surveys to 1979. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SWFC-23, 95 p.
- HUI, C. A.  
1979. Undersea topography and distribution of dolphins of the genus *Delphinus* in the Southern California Bight. *J. Mammal.* 60:521-527.
- LAAKE, J. L., K. P. BURNHAM, AND D. R. ANDERSON.  
1979. User's manual for program TRANSECT. Utah State Univ. Press, Logan, 26 p.
- LEATHERWOOD, S., A. E. BOWLES, AND R. R. REEVES.  
1983. Endangered whales of the eastern Bering Sea and Shelikof Strait, Alaska: Results of aerial surveys, April 1982 through April 1983, with notes on other marine mammals seen. Final report to NOAA/OCSEAP, Juneau, AK.
- LEATHERWOOD, S., I. T. SHOW, JR., R. R. REEVES, AND M. B. WRIGHT.  
1982. Proposed modification of transect models to estimate population size from aircraft with obstructed downward visibility. *Int. Whaling Comm.* 32:577-580.
- MILLER, R. G.  
1974. The jackknife—a review. *Biometrika* 61:1-15.
- NORRIS, K. S., AND J. H. PRESCOTT.  
1961. Observations on Pacific cetaceans of California and Mexican waters. *Univ. Calif. Publ. Zool.* 63:291-402.
- SMITH, T. D.  
1981. Line-transect techniques for estimating density of porpoise schools. *J. Wildl. Manage.* 45:650-657.
- SOKAL, R. R., AND F. J. ROHLF.  
1969. *Biometry*. W. H. Freeman and Co., San Franc., 776 p.